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On a NEW KIND *of* PORTABLE BAROMETER *for* MEASURING HEIGHTS.

By the Rev. JAMES ARCHIBALD HAMILTON, *D.D. M. R. I. A.*

THE acknowledged conveniency and accuracy of barometrical menſurations have induced thoſe who combine with a taſte for experimental philoſophy, mathematical ſkill and a talent for calculation, to aim at facilitating this work, by rendering the proceſs for determining the actual differences of altitudes within all poſſible limits, from barometrical obſervations made at different ſtations, ſimple and expeditious. Read Dec. 3, 1791.

THIS they have effected by a few general and obvious precepts and tables conſtructed on the baſis of a theory deduced from actual obſervation, and confirmed or amended by accurate and repeated trials; theſe helps, added to the variety of improvements made on the conſtruction of the portable barometer, and the excellent method methods contrived for its adjuſtment and uſe, have enabled enterpriſing and perſevering men to aſcertain facts with reſpect to the heights of mountains, which, though very material to the perfecting of geography and many other deſirable objects in natural philoſophy, would otherwiſe in all probability have long eluded our reſearches, from the inſupportable difficulty and fatigue that obſtruct all attempts at geometrical meaſurements of this kind ; but the inſtruments and tables are ſufficiently accurate and complete to enable the mechanical and expert, who will not be debarred by a little neceſſary labour of previous adjuſtment and concommitant attention, from applying both in their preſent forms to attain their end. Yet even theſe require ſome conſiderable object to reward their pains, and there are, beſides, very many to whom a general ſection of the country they live in, and even the particular altitudes of their own grounds, would be both uſeful and deſirable; who, nevertheleſs, are debarred from the enquiry by an apprehenſion that a good deal of nice and delicate adjuſtment is an almoſt inſurmountable difficulty in unpractiſed hands, and that where ſo much is required of previous ſtudy and knowledge, the reſults are ſo liable to uncertainty as not to be perhaps worth the labour of the inveſtigation; admitting then that in the hands of a De Luc or a Sauſſure the accuracy and preciſion of the adjuſtments of a Ramſden will be done ample juſtice to, yet ſtill, as we have not every where ſuch hands, ſuch inſtruments, or ſuch objects as Mountblanc to employ them on, it cannot ſurely be denied that it may be very deſirable, even as a philoſophical amuſement, to put within every perſon's reach the buſineſs of making an accurate ſection of a whole county, province or kingdom, whoſe greateſt elevations do not exceed two or three thouſand feet above the level of the ſea, of marking regularly and truly the ſeveral inequalities of the grounds, and of ſhewing their actual differences of heighth within a few inches, by an inſtrument of no comparative price, that requires in no caſe whatever the ſmalleſt adjuſtment, hardly any previous ſkill in its application; is liable to ſcarce any accident or error, and is not more cumbrous than a common walking ſtaff.

If it ſhall appear that ſuch an inſtrument, within the limits aſſigned, is capable of extreme accuracy, and anſwers equally well all the purpoſes of the complicated, expenſive and operoſe, I ſhould hope that this improvement would be favourably received by the more ſkilful and learned, and afford an incitement to others to enter upon an eaſy experiment that may lead to many valuable diſcoveries in the courſe of their reſearches.

I shall now proceed to the manner of making and uſing this kind of portable barometer, and ſhall add ſome remarks on the peculiar and conſiderable advantages of its conſtruction. It may be proper to premiſe that the principle on which this inſtrument acts is this; that corkwood is a ſubſtance, the pores of which afford a ready and free paſſage to the particles of air, while at the ſame time they are too ſmall to ſuffer thoſe of quickſilver to to eſcape, except indeed ſome particular and powerful means are uſed to force them through its interſtices.

The barometer conſiſts of a tube not much more than thirty inches long, an ivory cylinder about two inches in length, and upwards of one inch in diameter, open at one end, cloſed at the other by a cover that is to be fitted on with a ſcrew, ſo fine and true as to prevent the eſcape of any quickſilver when the inſtrument is put together.

A SOUND, clean and porous cork, of about three-fourths of an inch in length, and one in diameter, ſhould be very nicely fitted to enter with a moderate preſſure at the bottom of the ivory cylinder, which ſhould be turned ſo truly throughout that the cork may be puſhed up to the extremity of the open, where there ſhould be left a ſmall ſhoulder to ſtop the farther progreſs of the cork, and to retain it in its proper place. When the cork is in this ſituation it ſhould be carefully bored with a circular file to receive the end of the glaſs tube tightly through its axis, ſo that the end of the tube may riſe beyond it, and project about half an inch into the empty part of the cylinder, and that the axis of the tube, and of the cylinder, may be exactly in the ſame right line.

THE tube ſhould be then carefully filled in the uſual manner, and the mercury poured over the end into the ivory cylinder till ſuch a quantity is admitted as may be ſufficient, when the lid is ſcrewed down tight, to cover the end of the glaſs tube in any poſſible poſition of the inſtrument: to wit, when held either parallel, oblique, or perpendicular to the horizon, a bored mahogany ſtaff with a braſs ſcale and vernier, a thermometer caſe, and caps of braſs to ſlide or ſcrew on each end, is to be prepared to receive the barometer and its attached thermometer, which being firmly and carefully introduced and fitted to their places, the whole is completed and fit for uſe.

FIGURE I.

A B repreſents a ſection of the barometer longitudinally, when put together and ready for uſe. F the ivory cylinder. C D the ſcale, with a vernier that ſlides ſo as to cover the operture when the inſtrument is put by. E the attached thermometer in its caſe, G G the braſs caps that ſecures the ends.

FIGURE II.

A B repreſents a ſection of the ivory cylinder with its cork C, and its tube T S the ſurface of the mercury. M the maſs of mercury, E E the ſhoulders that keep the cork C in its place; and F F its bottom that ſcrews on tight.

To uſe the inſtrument, you have nothing to do, but taking it lightly between the finger and thumb of the right hand near D, fig. I. gently turn up the point A, and looking through oppoſite to the light (for the outer caſe is to be cut to give this advantage, and alſo for the purpoſe of a ſcale and vernier diviſion on each ſide) you will obſerve the mercury to ſink gradually and gently to its due ſtation; and with your left hand following the ſubſiding ſurface of the mercury with the bottoms of the vernier ſlide (which are to be made exactly ſquare and of the ſame length) determine their contact with the top of the quickſilver when ſettled, and finally read off the obſervation, on one or both ſides of the inſtrument. Note, for greater accuracy this proceſs may be repeated two or three times, and ſhould the ſeveral obſervations vary, a mean of all may be taken.

Remarks on the Conſtruction and Uſe of the Inſtrument.

REMARK I.

ON the conſtruction of this inſtrument very little need be ſaid, as it is ſo obviouſly ſimple and eaſily to be apprehended. It may not, however, be uſeleſs to remark that the author has, by the uſe of a variety of theſe inſtruments for a number of years, ſatisfied himſelf and ſeveral ingenious and philoſophical friends, that the permeability of cork to air, and at the ſame time its reſiſtance to the paſſage of mercury, is moſt ſatisfactorily aſcertained, a point which cannot be too ſtrongly inſiſted on in this buſineſs, as the ſucceſs of the experiment depends entirely on the truth of this fact; in making the inſtrument, great care ſhould be taken to provide ſound, ſmooth, and ſpungy corks, to fit the round of both tube and cylinder very accurately, and to be careful not to force them into their places too tight, which would not only endanger breaking the tube, but alſo make the riſe and fall of the mercury, on inverting the barometer, too tedious. It will be alſo requiſite, in filling the ciſtern, to obſerve accurately the quantity of mercury that will ſuffice to keep the end of the tube covered in all poſitions, and at the ſame time leave the greateſt poſſible room for the reception of the falling quickſilver.

REMARK II.

On the Adjuſtment of the Inſtrument.

THIS Inſtrument is adjuſted, once for all, at the time of making it, in the following manner:

MEASURE very exactly the inner diameter of the ivory cylinder, which ſhould be turned throughout perfectly true; the inſide of the cover very ſhallow and of the ſame dimenſions with the reſt of the cylinder. You are likewiſe to meaſure the diameter of the aperture of the glaſs tube, which ſhould be alſo choſen truly cylindrical and well drawn. Theſe diameters being known, a very eaſy calculation will ſhew what the correction of the ſcale muſt be within any aſſigned limits; that is to ſay, what the elevation of a fluid in a cylinder of one inch diameter will be by pouring into it the contents of another cylinder of one-tenth of an inch in diameter, and three inches or any other given quantity in height. There will in the preſent caſe be required another correction (viz.) an allowance for the ſpace occupied in the cylinder by the projecting part of the glaſs tube. Theſe calculations being made for every particular barometer, its ſcale ſhould be accompanied with a ſmall table of corrections for converting the obſerved differences of altitude into the true to be applied at reading off the obſervations.

But as ſome perſons may chuſe to conſtruct theſe barometers who could not rely on their ſkill in making theſe calculations, they may find the above correction mechanically, as follows: before you put the inſtrument together, let the tube exceed the required length, perhaps three or four inches: break off three inches, and reſerve them till the barometer is finiſhed; apply it in its caſe to the ſcale, and carefully note the height it ſtands at.

For greater ſecurity, let this obſervation be made three or four times, then take it out of the caſe or mounting, and opening the cylinder, without loſing any of the mercury, fill your reſerved tube of three inches, and pouring the contents into the cylinder, replace all in the mounting. Now obſerve the height the mercury ſtands at; the difference of this and the former height gives preciſely the effect on the level of the mercury in the ciſtern, occaſioned by the addition of three inches of the contents of the tube; and this quantity will ſerve as an argument to conſtruct a ſcale of correction for the inſtrument which cannot err.

It is to be obſerved, that when you have thus attained what may be called the error of the ſcale, you ſhould withdraw the mercury poured in, to leave the more room in the ciſtern, if wanted.

Example of the above Proceſs.

On conſtructing a barometer, with a cylinder of one inch in diameter, I obſerve the mercury to ſtand at 29, 0. I open the cylinder, and pour in three inches from a piece of the reſerved tube, replacing the whole as before; I obſerve that the mercury now ſtands at 29, 12. It is obvious, from this experiment, that had I carried the barometer, previous to this infuſion of mercury, to an height which would have occaſioned the deſcent of three inches of mercury into the ciſtern, that the effect would have been preciſely ſimilar, *i. e.* that the mercury would then ſtand at 26, 12; and of courſe, in eſtimating all heights, the interval found by this barometer is in the firſt inſtance to be increaſed in the proportion of ,04 of an inch for every inch the mercury falls in the tube. It is eaſy to apprehend that a table may be readily formed to make theſe allowances at ſight, as correct as can be deſired.

On the advantage of this adjuſtment it is to be obſerved, that being once found, it remains perfectly free from any poſſibility of alteration, as neither the form or capacity of the tube or ciſtern are liable to alter. It ſaves the trouble of pouring mercury in or out of the ciſtern; the inconvenience of leather bags, that are conſtantly liable to go out of order and waſte the mercury; and, beſides, gets rid of all the errors of adjuſtment, ariſing either from friction or reading off; which the obſerver is liable to in the uſe of the floating guage, or any other contrivance ſubſtituted in its room, that requires to be adjuſted at every ſeparate obſervation.

REMARK III.

On the Dimenſions of the Inſtrument.

As ſimplicity and portableneſs are the great advantages of this inſtrument, I would recommend the keeping the width of the aperture of the tube as much under as poſſible, as well to prevent accidental breaking from the weight of a thick column of mercury, as alſo to leave the more room for the deſcending mercury in the ciſtern. If the diameter of the tube is a full tenth of an inch, and that of the ciſtern 1, 2, there will be ample room to meaſure a height of 3000 feet, which is enough for any thing intended to be accompliſhed by this inſtrument. The ſhell of the glaſs ſhould be of ſtrong and tough metal, and the ſealing well annealed, as there is nothing but the gradual admiſſion of the air through the cork to check the force of the mercury againſt the top of the barometer on inverting it. It is alſo plain that the length of the tube ſhould be as little more than that of the greateſt uſual height of the mercury at the level of the ſea as poſſible, becauſe when the barometer is uſed all the ſuperfluous mercury that runs down from above the height will contract the neceſſary ſpace in the ciſtern.

REMARK IV.

On the Mercury.

THE mercury ſhould be perfectly well cleaned; this is beſt done by repeatedly waſhing it in a vial with ſucceſſive freſh waters, and when dried pouring it through a pin-hole made in a white paper cone.

THE mercury may (if required) be boiled in the tube; but I apprehend there are ſome conſiderable objections againſt this mode.

REMARK V.

On the Thermometers.

THE attention to the ſtate of the attached thermometer, ſo neceſſary in the uſe of any barometer for meaſuring heights, is particularly ſo in this, as from the ſize and material of the ciſtern or cylinder its dimenſions are liable to poſſible changes. To obviate this objection the ſides of the cylinder ſhould be made pretty thick and ſtrong, as otherwiſe they might be acted upon in ſome degree like Mr. De Luc's hygrometers, and a change in their dimenſions from expanſion or contraction might defeat the accuracy of obſervation. It were at all times deſirable, with every ſpecies of barometer, that the ſeparate obſervations ſhould as nearly as poſſible be made at the ſame temperature of the annexed thermometer. If this circumſtance is attended to the ſource of errors depending on this cauſe will entirely vaniſh.

REMARK VI.

On carrying and uſing the Barometer.

THE only ſafe way of carrying this inſtrument is with the point downwards; the attached thermometer is to be looſe in its caſe with a quill ſcale, and a bit of cork or cotton within the cap for its bulb to reſt on; in this way I have both on horſeback and in carriages conveyed this inſtrument ſafely for many hundred miles.

FROM the conſtruction it is evident that, if accurately made, they will hang truly plumb when inverted and held lightly between the fore-finger and thumb. But this obvious advantage does not preclude many contrivances which might be thought of to hang them in gimmals, or ſuſpend them in any manner that might be thought more adviſable. This and a great many varieties in the conſtruction, which might be adopted without interfering with the ſimplicity of the principle, I leave at large to the curious, and ſhall only add, that from continued and cautious experience it is manifeſtly certain that theſe barometers are as ſenſible and ſhew the ſmalleſt changes in the weight of the atmoſphere as accurately as thoſe whoſe ciſterns are actually open, and that I have tried them repeatedly againſt ſome of the ingenious and accurate Mr. Ramſden's provided with floating guages, verniers, &c. and the reſults have never varied two inches from each other in altitudes of above three hundred feet.

On Barometrical Menſuration.

THE inſtruments required for this purpoſe are two good barometers of a proper and ſimilar conſtruction, with two thermometers of Farenheit's ſcale to each, one attached to the barometer and covered in its caſe as near the mercury as poſſible, to determine the actual heat or cold and the conſequent expanſion or contraction of the mercury in the inſtrument. The other detached for obſerving the temperature of the air in the ſhade, and from thence to deduce the value in length of a column thereof equal in height to a given column of mercury in the barometrical tube.

☞ IF the heights to be meaſured are but ſmall, and the different ſtations acceſſible in a ſhort interval of time, one obſerver by going from place to place may determine them with ſufficient accuracy; but if either the heights or the intervals of the ſtations in diſtance make a conſiderable portion of time neceſſary to complete the obſervers, they ſhould unqueſtionably be made by ſeparate obſervations at the ſame inſtant of time, to be aſcertained either by ſignals or by a previous compariſon and adjuſtment of their ſeveral time-keepers.

The Things to be done are,

1ſt, To obſerve accurately the heights of the mercury in the barometer at the reſpective places of obſervation, and carefully to note the differences.

2d, To obſerve the temperature of the mercury in the barometer, by conſulting the attached thermometer of each barometer at the different places of obſervation.

3d, To note the temperature of the air, by obſerving alſo at each ſtation the ſtate of the detached thermometer in the ſhade.

THESE obſervations being carefully made, and the neceſſary allowances and calculations gone through, the reſult will give very correctly the difference of the actual height of *the two ſtations.*

Fig 1

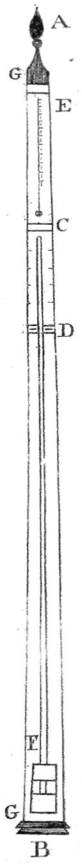
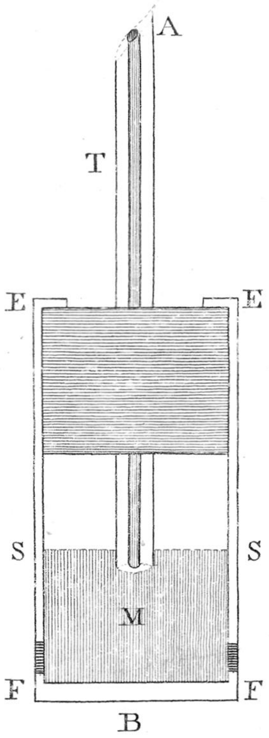
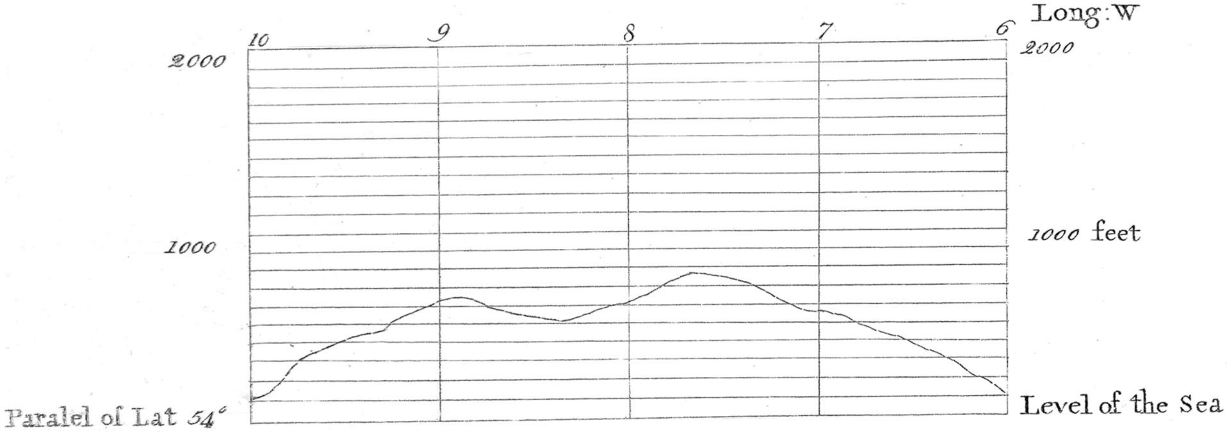


Fig 2





Barometrical Map of Four degrees Long:

To equate a given Column of Mercury in the Barometer ſo as to aſcertain its proportionate Length to a Column of 30 *Inches with a Temperature of* 55° *of* FARENHEIT'S *Scale.*

As the mercury in the barometer expands and contracts itſelf in proportion to the heat and cold of the atmoſphere, ſo that the ſpecific gravity of the metal is in fact different at different times, it is evident that the actual height of a column of the atmoſphere being given, if the temperature of the air as to heat and cold varies, the length of the rod of mercury ſupported by ſuch a given column will be longer or ſhorter in proportion to the greater or leſſer degree of atmoſpheric heat. To aſcertain therefore the variations in columns of mercury of different lengths, ariſing from the different temperatures of the atmoſphere, ſome given length and given temperature muſt be fixed on, as the term or ſtandard of compariſon. 30 inches of mercury, and 55° of Farenheit's thermometer, have been generally choſen for this ſtandard, as the one is pretty nearly the mean height of the mercury in the barometer at the level of the ſea, the other the point of the ſcale of Farenheit's thermometer, uſually in theſe climates marked temperate. If either or both of thoſe terms vary, the obſerved length of any column muſt be equated to reduce it to what it would be if the mercury ſtood at 30 in a barometer at the level of the ſea, and the thermometer at 55°. It has been proved, by very exact and repeated experiments, that the barometer, ſtanding at 30 inches, the expanſion produced in the whole column by a change of one degree of heat in the thermometer, is equal to ,00304 of an inch. On this calculation, for a variation of 33° of the thermometer above or below 55° you muſt retrench or add ,1 of an inch from or to the obſerved height of a column of 30 inches, and on the ſame principle it will be found that a variation of each degree of the thermometer above or below 55° expands or contracts the mercury ,00101333 of an inch in every column of the length of ten inches. The mercury therefore ſtanding at 30 inches, the correction for each degree of variation of temperature above or below 55° is in the proportion of ,1 of an inch to a variation of 33°; call this correction C. If the height of the mercury in the barometer alſo varies from 30, call the obſerved height A, and the correction ſought X, then ſay 30: A:: C: X, therefore $\frac{AC}{30}=X$. To abridge theſe calculations a table has been conſtructed on the foregoing principles, which ſhews in decimals of an inch the effect of the expanſion or contraction for each ſingle degree of the thermometer above or below 55° upon the number of inches of ♀ marked in the firſt column.

T A B L E I.

Inches of ♀	
10	,001013
20	,002027
30	,003040
40	,004053
50	,005067
60	,006080
70	,007093
80	,008107
90	,009120

To uſe this table, write out the decimals correſponding to the given height of the barometer in inches and decimal parts, lowering the places of the decimals for the odd inches and tenths above or below 30 inches. Add all together, and multiply the ſum by the difference in degrees of the attached thermometer from 55°. This product applied to the obſerved height—or+as the temperature of the barometer was above or below 55°, will give the correct height for the mean temperature. Note, this correction is to be regulated by the attached thermometer at every ſtation and obſervation; and is intended with a view to aſcertain and allow for the actual temperature of the mercury in the ſeveral barometers.

As the expanſive power of heat and the contraction of cold do alſo ſo affect the atmoſphere, that as theſe cauſes vary a longer or ſhorter column of the atmoſphere, and of courſe different intervals of height, will be indicated at different times by a column of mercury of the ſame length, and reduced as above to a ſtandard temperature.

It therefore becomes neceſſary to correct the differences of heights ſhewn by the reduced columns of mercury at the different ſtations, by a calculation founded on the effects of heat and cold on the atmoſphere. The argument for this calculation is the mean temperature of the atmoſphere, obtained by adding together the heights of the mercury in the detached thermometers at the different ſtations, and dividing the ſum by 2. This mean may be called an imaginary temperature.

TABLE II.

1	,0024
2	,0048
3	,0072
4	,0097
5	,0121
6	,0148
7	,0170
8	,0194
9	,0218

As the ratio of the decreaſe of denſity in the atmoſphere is only conformable to the tabular logarithms and Engliſh meaſure in the temperature of 32° nearly of Farenheit's ſcale, table the ſecond is calculated to ſhew the correction required for the rarefaction of each foot of the atmoſphere for a ſingle degree of heat above 32° in decimals of a foot, and may be applied to any number of feet, as for 4444,4

Example	4000	9,72000
	400	,97200
	40	,09720
	4	,00972
	,4	,00097

FROM the preceding obſervations and tables are deduced the following rules to determine the actual differences of the heights of the places of obſervation.

RULE I.

REDUCE the temperature of the mercury in each barometer to the mean temperature at each ſtation.

RULE II.

REDUCE the obſerved temperatures of the atmoſphere at the different ſtations to the imaginary uniform temperature.

RULE III.

SEEK the common logarithms of each obſerved height, corrected by rule I. in inches and tenths, and reject the index.

CUT off the firſt four figures with a comma, and place the logarithms one under the other. The differences of the parts of theſe logarithms, preceding the comma, ſhew the actual differences of the heights of the ſtations in Engliſh fathoms; and the differences to the right of the comma in decimals of a fathom, provided the mean temperature of the atmoſphere (that is, the imaginary uniform temperature) be nearly 32°; otherwiſe call this reſult the approximate height. Multiply the approximate height by 6 to reduce it to feet.

RULE IV.

SEEK in the table, for correction of rarefraction of the atmoſphere, the numbers anſwering to the numbers of feet in the approximate height. Multiply the ſum of theſe numbers by the difference in degrees and decimals of a degree between the imaginary uniform temperature and 32°. If the imaginary unform temperature exceed 32°. add this product to the approximate height, and the ſum will be the actual difference of the heights of the ſtations in Engliſh feet. This method of inveſtigation is deduced from a paper of Dr. Maſkelyne's, founded on the calculation of Mr. De Luc and Sir George Shuckburgh; and to make it more practicable and leſs complicated the algebraic demonſtrations are omitted. If General Roy's calculations of the effects of heat and cold on the atmoſphere and on the mercury be more accurate than any former ones, they may be eaſily adapted to theſe *formulæ*, and tables calculated from them.

POSTSCRIPT.

THIS communication on the ſubject of the portable barometer was ſome time ſince ſubmitted to the conſideration of the learned and accurate friend whoſe valuable correſpondence accompanies it; and whatever its intrinſic value may be, the author has no doubt that, from its having ſuggeſted the following curious hints and obſervations, it is well worth being offered to the notice of the Academy. He is himſelf convinced, by the experience of many years, that it will act effectually and well in the form he deſcribes, which, as being by far the moſt ſimple, he therefore propoſes as moſt eligible. He muſt confeſs that in making theſe inſtruments a conſiderable degree of nicety is required, to adjuſt the cork to the box and tube in ſuch a manner, as to allow the air a ready acceſs to the ſurface of the mercury, and at the ſame time completely confine it in its box; and it has often occurred that by compreſſing the cork too tightly the riſe and fall of the mercury have been more gradual than were to be wiſhed. To remedy this, the author thought of, and put in practice, ſome contrivances that were fully ſufficient; but as he thinks none of them ſo complete as that ſuggeſted by his correſpondent, he will not increaſe the length of this paper by inſerting any of them. Having made numbers of the portable barometers in their ſimpleſt forms, compared their variations with thoſe of the very beſt open barometers, and found them to correſpond exactly; having alſo carried them ſome thouſands of miles, moſtly in a carriage, but often on horſeback, without injury to any of them, he is inclined to think that, in the improved form, they ſhould be adopted for general uſe, and may be readily and univerſally made upon the plan of a corrected ſcale, as ſet forth in the following letter by his ingenious friend. Should any perſon wiſh to try the experiment therein mentioned, relative to the abſorption of air by mercury, it will make it ſtill more deciſive and ſatisfactory. If after the ciſtern is finally cloſed, it, and about half an inch of the tube immediately adjoining it, be dipped in melted wax and ſuffered to cool, and this repeated three or four times.